Active Carbon and Biological Properties as Indicators of Soil Quality in Dryland Mediterranean Farming

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Abstract: Soil quality indicators of changes derived from different tillage managements are required. We studied the short (3 years) and long-term (16 years) effects of conservation tillage (CT), in comparison to traditional tillage (TT), on soil organic carbon fractions (total organic carbon, TOC and active carbon, AC) and biological properties (microbial biomass carbon (MBC) and β-glucosidase activity) on a sandy clay loam soil (Xerofluvent) located in semi-arid SW Spain. A rainfed crop rotation (cereal-sunflower-legumes) was established in both trials. Soil samples were taken in flowering (in March) and after harvesting (in July) of a pea crop and collected at three depths (0-5, 5-10 and 10-20 cm).

Contents of AC and MBC in the long-term and content of AC in the short-term were higher in CT than in TT in the upper layer. In July sampling, β-glucosidase values were higher at the top-soil under CT in both trials. The studied parameters decreased with increasing depth in both tillage systems (TT and CT) and in both trials. β-Glucosidase values presented high correlation coefficients with AC and TOC contents in the long-term trial. There was not correlation for both TOC and MBC with others parameters in the short-term trial. In this study, the AC content is reported as the most sensible and reliable indicator for assessing the short- and long-term impact of CT on soil quality under our conditions.

Keywords: sustainable agriculture; tillage; soil organic carbon; soil active carbon.

INTRODUCTION and LITERATURE REVIEW

Conventional management based on excessive tillage increases soil erosion and compaction that contribute to soil fertility loss. For that reason, profitable and respectful environmental agricultural practices such as conservation agriculture are being promoted in the European Union (EU). Conservation agriculture attaches great importance to the maintenance of soil structure, productivity and biodiversity under three basic principles: minimum soil disturbance, soil covering and crop rotation. Specially, in dryland agriculture in the

Mediterranean area no tillage systems have greatly reduced both soil loss rates by erosion and production costs (Ordóñez-Fernández *et al.,* 2007) and they have also increased soil organic carbon (Murillo *et al.,* 2006).

In general, the long-term effects of soil management practices on the size and activity of the microbial biomass have been found to be closely related to changes in total soil organic matter content (Franzluebbers and Arshad, 1996). However, in short-term field experiments, it is often difficult to detect changes in soil organic matter following the implementation of new management practices (Álvarez and Álvarez, 2000). In general soil organic matter change slowly and several years are necessary to obtain significant differences, while biological parameters could be more sensitive and rapid indicator of changes in soil management practices (Nannipieri *et al.,* 1990).

Although several studies have been published comparing the effects of different tillage systems on soil biological properties (De la Horra et al., 2003; Roldán et al., 2005), there is comparatively less information (short- and long-term) on the soil biological status found in rainfed-agriculture under semi-arid Mediterranean conservation agriculture systems. Our objective was to study the evolution of the soil organic C fractions (TOC and AC), MBC, and β-glucosidase activity in short- and long-term field experiments in which CT and TT was compared. We hypothesised that CT would have a positive effect on soil quality by increasing soil organic matter and enhancing soil microbial functionality, especially over the long-term. We also discussed these parameters as reliable indicators of change in soils with both long and short histories of conservation management.

MATERIAL and METHODS

2.1 Localization of the experimental area and tillage systems

Short- and long-term field trials using soil conservation management have been conducted on a sandy clay loam soil, Entisol (Xerofluvent, Soil Survey Staff, 1999), at the experimental farm of the 'Institute of Natural Resources and Agrobiology at Seville (IRNAS-CSIC) (37º 17′ N, 6º 3′ W) (Spain). The soil has a pH of around 7.8 (calcareous).

An area of about 2500 m^2 was selected for establishing the experimental plots in 1991. In autumn of that year, wheat was grown. After harvesting the wheat in June 1992, the area was divided into six plots of approximately 300 m^2 (22 m x 14 m) each in a completely randomised experimental design (three replicates per treatment). In 2005, a short-term experiment was established in the same area following the same experimental design, but with 200 m^2 plots.

Two tillage treatments were compared: TT and CT. In both short- and long-term trials, TT consisted of mouldboard ploughing (to a depth of 30 cm). In the long-term trial, CT was characterized by a reduction in the number of tillage operations (retaining only chiselling at a depth of 25-30 cm) as well as by leaving the crop residues on the soil surface. CT in the short-term trial was characterized by no tillage in which the residue is left on the soil surface.

At the beginning of the long-term trial, a wheat (*Triticum aestivum*, L.)–sunflower (*Helianthus annus*, L.) crop rotation was established for both TT and CT. However, in 2005, a fodder pea crop (*Pisum arvense*, L.) was included in the rotation for both tillage methods. Thus, from 2005 on, the annual crop rotation consisted of a basic cereal-sunflower-legumes rotation for both trials and treatments.

The sunflower and fodder pea crops were not fertilized (as is traditional in this zone), while wheat received deep fertilization with 400 kg ha^{-1} of a complex fertilizer (15N–15P_2O_5– 15K_2O) before sowing and a top dressing with 200 kg ha^{-1} urea (46% N). Since 2002, fertilization has been reduced to 100 kg ha^{-1} (fertilizer complex) with no top dressing fertilizer. Weeds are controlled by tillage in TT and by the application of pre-emergence herbicides in CT, at a rate of 2 L ha^{-1} trifluraline (18%) (sunflower) and 4 L ha^{-1} glyphosate (18%) (wheat, fodder pea).

2.2 Sampling and soil chemical and biochemical analysis

In both short- and long-term field trials, soil sampling was carried out in March 2008 during the pea crop-growing period and in July 2008 after harvesting at three sites of each individual plot (a total of nine samples per treatment); soil was collected at three depths: 0-5 cm, 5-10 cm and 10-20 cm. The moist field soil was sieved (2 mm) and divided into two sub-samples. One was immediately stored at 4 ºC to assaying for microbiological and enzymatic activities. The other was air-dried for chemical analysis.

TOC was analysed by dichromate oxidation and titration with ferrous ammonium sulphate (Walkley and Black, 1934). AC was determined by oxidation with 0.2 M $KMnO_4$ in 1M $CaCl_2$ (pH 7.2) and non-reduced Mn^{7+} was colorimetrically determined at 550nm (Weil et al., 2003).

MBC content was determined by the chloroform fumigation-extraction method modified by Gregorich et al. (1990). β-Glucosidase activity was measured as indicated by Eivazi and Tabatabai (1988).

Results were based on the oven-dried weight of the soil.

2.3 Statistical analysis

Statistical analyses were carried out using SPSS 11.0 for Windows, and the results were expressed as mean values. Significant differences between management systems (TT, CT) were shown by a Student's t-test at $p<0.05$. One-way analysis of variance (ANOVA) was carried out to assess the spatial variability of all parameters for each individual treatment.

RESULTS

In the long-term trial, only AC and MBC mean values were statistically different between treatments at 0-5 and 5-10 cm depth in March. However, significant differences between treatments were observed only for TOC, AC, MBC and β-glu at 0-5 cm depth in July (Table 1), with the highest values in soils under CT.

Table 1.Mean values of total organic carbon (TOC), active carbon (AC), microbial biomass carbon (MBC) and -glucosidase activity in soil under traditional tillage (TT) and conservation tillage (CT) in the long-term experiment. Results of a one way analysis of variance for each soil property ([a] p< 0.05) at the different depths are also included.

		March 2008					July 2008				
	Treatment	**Depth (cm)**					**Depth (cm)**				
		0-5	**5-10**	**10-20**	**F (2,24)**	**[a]P value**	**0-5**	**5-10**	**10-20**	**F (2,24)**	**[a]P value**
TOC	**TT**	9.84	9.03	8.23	0.43	0.66	9.30	9.26	8.08	1.12	0.38
	CT	10.8	8.87	8.65	3.70	0.06	12.7*	9.35	7.62	50.48	0.00 [a]
AC	**TT**	780	694	695	3.02	0.09	700	702	698	0.37	0.70
	CT	1680*	1039*	693	9.54	0.006[a]	1380*	704	694	40192	0.00 [a]
MBC	**TT**	814	806	780	0.15	0.86	406	387	325	1.42	0.31
	CT	1058*	978*	879	5.44	0.03[a]	654*	405	283	47.6	0.00 [a]
Glu	**TT**	140	84.2	55.6	4.94	0.04[a]	122	115	84	0.92	0.44
	CT	169	108	98.8*	13.5	0.002[a]	236*	136	66	15.2	0.004[a]

Differences between treatments are indicated by (*) (p< 0.05).

TOC: gkg^{-1}; AC and MBC: mgkg^{-1}; Glu: β-glucosidase activity (mg p-nitrophenol kg^{-1} dwt h^{-1}).

Table 2. Mean values of total organic carbon (TOC), active carbon (AC), water soluble carbon (WSC), microbial biomass carbon (MBC) and -glucosidase activity in soil under traditional tillage (TT) and conservation tillage (CT) in the short-term experiment. Results of a one way analysis of variance for each soil property ([a] p< 0.05) at the different depths are also included.

		March 2008					July 2008				
	Treatment	**Depth (cm)**					**Depth (cm)**				
		0-5	**5-10**	**10-20**	**F (2,24)**	**[a]P value**	**0-5**	**5-10**	**10-20**	**F (2,24)**	**[a]P value**
TOC	**TT**	9.4	9.6	9.22	1.93	0.20	9.49	9.22	9.32*	0.13	0.88
	CT	9.98	9.54	9.53	0.07	0.92	9.46	8.10	7.72	3.91	0.08
AC	**TT**	705	692	644	2.12	0.17	704	704	702	0.80	0.49
	CT	1368*	700	696	42638	0.00[a]	1360*	696	692	13417	0.00[a]
MBC	**TT**	791	790	550	0.34	0.72	472	363	362	1.56	0.28
	CT	354	156	127	1.78	0.22	509	360	291	10.3	0.01 [a]
Glu	**TT**	97.2	71.6	48.2	9.15	0.007[a]	81.6	83.7*	85.3*	0.14	0.87
	CT	103	50.1	36.5	16.7	0.001[a]	106	55.2	40.2	23.5	0.001[a]

Differences between treatments are indicated by (*) (p< 0.05).

TOC: gkg^{-1}; AC and MBC: mgkg^{-1}; Glu: β-glucosidase activity (mg p-nitrophenol kg^{-1} dwt h^{-1}).

AC, MBC and β-glu mean values in March and TOC, AC, MBC and β-glu values in July showed differences between the different soil depths in soils under CT (Table 1).

In the short-term trial, only AC mean values presented statistical differences between treatments (CT and TT) at a depth of 0-5 cm in both sampling periods (Table 2). In the July samples, significant differences was observed in β-glucosidase values between treatments at 5-10 and 10-20 cm depth, showing the highest valus in soils under TT (Table 2), with the highest values in soils under CT. Under conservation tillage, significant differences between different depths were found for AC and β-glu in the March samples and for AC, MBC and β-glu in the July samples (Table 2).

On the whole, we observed a decrease in the studied properties as depth increased in both trials (long- and short-term) and in both treatments (TT and CT) (Tables 1 and 2).

DISCUSSION

Conservation tillage systems have been shown to increase soil organic matter at higher levels than traditional tillage (De la Horra et al., 2003; Madejón et al., 2007; Melero et al., 2008). In short-term studies, several authors have found an increase in TOC in the top layer when using NT in the first three years of transition from TT to NT (Muñoz et al., 2007). However, Liang et al. (2007) reported that in the short-term (3-year), NT tended to stratify TOC, but did not lead to a significant increase in TOC in topsoil (0-5 cm) as compared to TT. In our experiments, we recorded a noticeable increase in TOC in the soil upper layer (0-5 cm depth) only under CT (compared to TT) in the long-term trial (1.1 fold in March and 1.4 fold in July). These increases were not found in the short-term trial. The highest accumulation of total organic carbon at the surface using the CT system may be associated with the high input of crop residues left on the soil surface and with their slower decomposition processes (Roldán et al., 2005). In general, these results suggest that CT is an effective soil management technique for increasing sequestration of soil C, especially in the long-term.

Monitoring soil properties is a key point for the technical changes implied by CT. Thus, suitable indicators that indicate tillage-induced changes are required (Murillo et al., 2006). One of them may be the stratification ratio for TOC with soil depth (Franzluebbers, 2004). Soils with low inherent levels of organic matter can be the most functionally improved with conservation tillage (Franzluebbers, 2004). Although in this study the data of stratification ratio of TOC and AC are not shown. AC was the only soil property that showed a significant increase in the topsoil in both trials, with a significantly greater stratification ratio under CT than under TT. Thus, this study shows that under our experimental conditions, AC content is the most sensible and reliable indicator for assessing the impact of different soil management techniques on soil quality for both the short and long-term. Oyonarte et al. (2007) also proposed AC as a good indicator of the organic fraction in environmental monitoring programmes for arid environments.

The distribution of MBC may be related to the placement of crop residues. Álvarez et al. (1995) observed marked stratification in total soil microbial biomass and activity as a consequence of the application of NT to previously tilled soils in long-term experiments. Álvarez and Álvarez (2000) reported that total microbial biomass did not reflect the changes in the management of residues at 0-5 cm depth in the first crop cycle after implementing NT. In contrast, Gupta et al. (1994) found higher values of microbial biomass in the first 5 cm of the soil profile under NT than under CT after one year of conservation management. Our results showed more MBC in the upper layers for soils under CT in the long-term trial, whereas the reported results in the short-term trial reflect those obtained by Álvarez and Álvarez (2000).

In general, in both trials (short and long-term),β-glucosidase activity was found to be higher under CT than under TT. The same results have been observed by several other authors (De la Horra et al., 2003; Roldán et al., 2005). Besides, β-glucosidase was the soil enzymatic activity with more pronounced statistical differences between depths under conservation tillage in both trials and in both sampling periods. The same finding has been observed by other authors as well (De la Horra et al., 2003). This can be associated with a decrease in the easily decomposable organic C contents with depth under CT.

CONCLUSION

In our study, conservation tillage promoted an accumulation of crop residues at soil upper layers, increasing the storage of organic matter and improving biological properties, especially in the long-term. Thus, conservation tillage may contribute to the long-term sustainability of agricultural ecosystems under dryland semi-arid Mediterranean conditions.

In both trials, active carbon content was an appropriate soil indicator of changes by different soil tillage systems, showing a significant increase under conservation tillage. Therefore, active carbon could be utilised as a sensible and early warning indicator for assessing the impact of soil quality under conservation tillage.

REFERENCES

Álvarez, R., Díaz, R.A., Barbero, N., Santanatoglia, O.J., Blotta, L., 1995. Soil organic carbon, microbial biomass and C-CO_2 production from three tillage systems. Soil Till Res. 33, 17–28.

Álvarez, C.R., Álvarez, R., 2000. Short-term effects of tillage systems on active soil microbial biomass. Biol Fertil Soils. 31, 157-161.

De la Horra, A.M., Conti, M.E., Palma, R. M., 2003. B-glucosidase and proteases activities as affected by long-term management practices in a Tepic Argiudoll soil. Comm. Soil. Sci. Plant Anal. 34, 2395-2404.

Eivazi, F., Tabatabai, M.A., 1988. Glucosidases and galactosidases in soils. Soil Biol.Biochem. 20, 601-606.

Franzluebbers, A. J. and Arshad, M. A., 1996. Soil organic matter pools during early adoption of conservation tillage in northwestern Canada. Soil Sci. Soc. Am. J. 60, 1422–1427.

Franzluebbers, A.J. 2004. Tillage and residue management effects on soil organic matter. In: Soil Organic matter in sustainable agriculture. pp 227-268. Magdoff, F and Weil, R.R (eds). CRC Press LLC. New York.

Gregorich, E.G., Wen, G., Voroney, R.P., Kachanoski, R.G., 1990. Calibration of rapid direct chloroform extraction method for measuring soil microbial biomass C. Soil Biol. Biochem. 22, 1009–1011.

Gupta, VVSR., Roper, MM., Kirkegaard, JA., Angus, JF., 1994. Changes in microbial biomass and organic matter levels during the first year of modified tillage and stubble management practices on a red earth. Aust. J Soil Res. 32:1339–1354.

Liang, A.Z., Zhang, X.P., Fang, H.J., Yang, X.M., Drury, C.F., 2007. Short-term Effects of Tillage Practices on Organic Carbon in Clay Loam Soil of Northeast China. Pedosphere. 17(5), 619-623.

Madejón, E., Moreno, F., Murillo, J.M., Pelegrín, F., 2007. Soil biochemical response to long-term conservation tillage under semi-arid Mediterranean conditions. Soil Till. Res. 94, 346-352.

Melero, S., Vanderlinden, K., Ruiz, J.C., Madejón, E., 2008. Long-term effect on soil biochemical status of a Vertisol under conservation tillage system in semi-arid Mediterranean conditions. Eur. J. Soil Biol. 44, 437-442.

Muñoz. A., López-Piñeiro, A., Ramírez, M., 2007. Soil quality attributes of conservation management regimes in a semi-arid region of south western Spain. Soil Till. Res. 95, 255-265.

Murillo, J.M., Moreno, F., Madejón, E., Girón, I., Pelegrín, F., 2006. Improving soil surface properties: a driving force for conservation tillage under semi-arid conditions. Span. J. Agric. Res. 4, 97-104.

Nannipieri, P. Grego, S. Ceccanti, B., 1990. Ecological significance of the biological activity in soil. In: Soil biochemistry vol 6 (Eds G. Stotzky & J.M. Bollag). Pp 293-355. Marcel Dekker, New York.

Ordoñez-Fernandez, R., Gonzalez-Fernandez, P., Giráldez-Cervera, J.V., Perea-Torres, F., 2007. Soil properties and crop yields alter 21 years of direct drilling trials in southern Spain. Soil Till. Res. 94, 47-54.

Oyonarte, C., Mingorance, MD., Durante, P., Piñero, G., Barahona, E., 2007. Indicators of change in the organic matter in arid soils. Sci Total Environ. 378, 133-137.

Roldán, A., Salinas-García, J.R., Alguacil, M.M., Díaz, E., Caravaca, F., 2005. Changes in soil enzyme activity, fertility, aggregation and C sequestration mediated by conservation tillage practices and water regime in a maize field. Appl Soil Ecol, 30, 11-20.

Soil Survey Staff., 1999. Soil Taxonomy, 2nd ed., USDA Ag. HBK. 437, Washington.

Walkley, A., Black J.A., 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 37, 29-38.

Weil, R.R., Islam, K. R., Stine, M.A., Gruver, J.B., Samson-Liebig, S.E., 2003. Estimating active carbon for soil quality assessment: A simplified method for laboratory and field use. Am J. Altern Agric. 18, 3-17.